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Utilization of ferrochrome slag in concrete production

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Abstract. Ferrochrome slag is waste resulted from the manufacture process of ligature melting. It is a porous material of dark grey-green colour with 2530 kg/m^3 density and the open pores size from 1mm to 5 mm. After crushing crushed slag possesses the following characteristics or properties, namely: the least grain coarseness is 20 mm, the largest one is 120mm, the needle and plane grain content is 25.5%, so it refers to ordinary group of crushed stone, its crushability grade is M800, attrition grade AI and frostproofness is F25. Screenings or riddlings obtained by crushing and fractioning of slag possess gradation factor 2.9 and it refers it coarse sand group of class II. Concrete mixes have been investigated by using granite aggregates and ferrochrome ones. It is determined that mixes containing ferrochrome aggregate are stiffer than the traditional ones. In this case strength characteristics of the experimental concretes are 1.7 times higher than those of the traditional concretes. When evaluating approximate cement consumption for concrete made of ferrochrome slag aggregates it was established that such concrete possesses strength of B30 class, but by using granite aggregate in the concrete mix result in strength of B20 class.

1. Introduction

Metallurgy and associated with it mining complex takes one of the leading places both in the mineral raw materials mined and the recycled one per ton of the finished products among other branches of industry. Slags, their chemico-mineralogical composition and physico-mechanical properties allow to consider them as a valuable raw material to produce building materials. They are formed as by-products at the main technological process stages of ferrous and non-ferrous metals production. Since the geological conditions of ferrous metals deposits worked out become more complicated from year to year and their regular content in mineral raw material decreases, the increase of mining volume and ores recycling require more and more substantial expenses. On the one hand the economy or saving every ton the mineral raw material is a worthwhile matter, on the other hand the damage is becoming increasing perceived because the complex utilization of the mineral raw material is not fully used. Therefore, more wide and complex utilization of the mineral raw material is one of the key problems of technical progress in non-ferrous metallurgy, its solution practically involves the increased level of metals production. All these problems result in razing waste volume both in metallurgical and mining complexes and consequently the pollution of environment. The issue of waste recycling of both complexes is of vital importance for all highly developed industrialized countries [1–5]. In Russia they are generally utilized as aggregates or fillers [6–9].

To transport waste (slags) into disposal area is not profitable, because presents great material expenses as to their storage. Metallurgical plants, as a rule, prefer to crush such slags and suggest to use them as coarse aggregate, but fine fractions resulting from crushing are removed and wasted. Cast

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crushed slag as to its physico-mechanical properties is as good as natural dense crushed stones for effective types of heavy concrete aggregates [10].

Ferro-chrome slag from OOO Kluchevskaya concentrating or dressing mill (KCM) is one of the waste of non-ferrous metallurgy resulted from ligature. There exist technologies of returning a number of wastes such as ferrous slags, melts and non-standard metals into production [11]. However, this fails to solve the recycling problem completely though the waste quantities are decreased. In this country there are 6 specialized mills to produce ferroalloy products, four of them are located on the territory of Sverdlovsk region [12]. This fact counts in favour of utilization such wastes urgently and without delay.

2. Raw materials and methodology

Ferrochrome slag from KCM is the material of dark grey-green colour, 2530kg/m^3 density, hardness 7–8 on Moss scale, water adsorbtion 2.63% and the developed surface on which there are open pores from 1 to 5mm in size which are distinctly seen. 3 laboratory slag samples have been investigated. These samples differ in chemical composition, but possessquite enough close values of basility M_b which is equal to 1.41 on the average (table 1). Because M_b is larger than 1, ferrochrome slag is referred to this group.

Table 1. Chemical composition of slag.

Sample No	Oxide content in mass%							M_b
	SiO_2	Al_2O_3	FeO	CaO	MgO	Cr_2O_3	others	
1	27.5	7.0	0.2	33.0	16.1	14.3	1.9	1.42
2	30.8	7.0	10.7	34.0	17.0	0.2	0.3	1.35
3	26.7	7.5	14.9	31.0	18.7	0.2	1.0	1.45

Portland cement CEM II/A-S manufactured by OAO Sycholozhcement, granite broken stone of 10-20 mm fraction and sand from granite crushing riddling of Shartash deposit have been used when heavy concrete content was selected (table 2). To obtain concretes ferrochrome slag was crushed up to the same fractions.

Table 2. Characteristics of aggregate.

Material	The largest grain size, ∅mm	The fineness modulus of sand	Bulk density, kg/m^3	Grain density, kg/m^3
Slag crushed stone	120	–	1260	2530
Slag sand	–	3.0	1640	2530
Crushed granite stone	20	–	1320	2600
Sand from granite crushed riddlings	–	2.1	1520	2620

The grain density of materials differs, but not so much. It is explained by the more developed surface of ferrochrome slag the open pores 1−5 mm in size are distinctly seen on it. The volume of open pores of granite crushed stone is 0.41%, but the volume of the crushed slag ones is 1.82%. Physico-mechanical testings of ferrochrome slag were carried out according to Russian Standard 8269.0 and 8735 to conform the requirements to Russian Standard 5578 ‘Crushed stone and sand for slag of ferrous and nonferrous metallurgy for concretes. Technical conditions’ and Russian Standard 3344 ‘Slag crushed stone and sand for road building. Technical conditions’.

Calculation of concretes content was done according to the method of absolute volumes. Concrete mixes and concretes proper were examined in accordance with Russian Standard 1273.0 ‘Concretes. General requirements to the methods to determine density, moisture, water adsorbtion, porosity and water permeability’, Russian Standard 10180 ‘Concretes. The methods of strength determination by the control samples’, to conform the requirements to Russian Standard 26633 ‘Heavy and fine-grained concretes. Technical conditions’.

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3. Results of experiments and discussion

As a coarse aggregate ferrochrome slag possesses the following characteristics including: needle and grain forms content is 25.5% and due to this content, it refers to the ordinary crushed stone group, the content of dust particles is 0.09 and the crushability grade is M800, the attrition grade is AI and the frost resistance is F25 (table 3). Thus, ferrochrome slag meets the requirements standard 3344 ‘Slag crushed stone and sand for road building. Technical conditions’ and it can be recommended for utilization as coarse aggregate in road building.

Table 3. Physic-mechanical properties of crushed ferrochrome slag.

Quality indices	Value	Conclusion Russian Standard 3344–83
d the largest	120	meets
d the least	20	meets
Group of grains as to their from	ordinary	meets
Content of dust particles, mass %	0.09	meets
Water adsorption, %	1.44	is not normalized
Crushability, mass %	18.96	markM800
Attrition, mass %	22.13	markAI
Frost resistance, mass %	9.96	mark F25

Being the coarse aggregate for concrete ferrochrome slag waste as to its content of plane and needle form refers to the third group having the crushability mark M600, the other characteristics conform to table 3, speaking about its capability or practicability to be used as broken slag aggregate when producing concrete mix. Riddlings obtained as a result of slag crushing refers to the sand group of class II, it possesses the gradation factor 2.9 and meet Russian Standard 5578 requirements accordingly and it can be considered as slag sand.

Four concrete mix proportions or concrete mixes have been calculated in accordance with mark M350 which was predetermined or prescribed, and the cone sedimentation mobility is from 2 to 4 cm (table 4). The concrete mixes were distinguished by aggregates proper. Four aggregates were tested, namely:

– The first aggregate was the control one, it consisted of the granite crushed stone and its riddling after crushing.

– The second aggregate was made of the granite crushed stone and riddling from ferrochrome crushing.

–The third aggregate was made of ferrochrome slag and riddling from granite crushing.

– The fourth aggregate was made of ferrochrome slag and its riddling after crushing.

According to the calculation trial batches or trial mixes and their correction have been designed (table 5).

Placeability of concrete mix was assessed or evaluated by standard cone sedimentation. Due to this index all concrete mixes have placeability mark P1, but experimental concrete mixes are stiffer because their standard cone sedimentation is from 2.0 cm to 2.5 cm against 3.5 cm of the control concrete mix. This is explained by the fact that ferrochrome slag has more developed surface in comparison with the granite one, therefore, its water consumption is higher.

Comparing concrete mix No 1 with No 3 and No 4 ones it is seen and understandable that concrete production consumes more coarse aggregate and less fine one during the last years. This is explained by the fact that there exists the possibility to economize natural raw material when producing concrete. Besides it should be noted that the experimental mixes require less cement consumption which is the most expensive concrete mix component.

Table 4. Calculated contents of concrete mixes at W/C=0.51.

Content No	Material consumption per 1 m^3 of concrete mix, kg						Calculated density of concrete mix, kg/m^3
			granite		ferrochrome slag		
	water, l	cement	crushed stone	sand	crushed stone	sand	
1	170	335	1123	726	–	–	2354
2	170	335	1123	–	–	752	2380
3	170	335	–	776	1068	–	2349
4	170	335	–	–	1068	750	2323

Table 5. Factual contents of concrete mixes when W/C=0.51.

Content No	Material consumption per 1 m^3 of concrete mix, kg						Density of concrete mix, kg/m^3
			granite		ferrochrome slag		
	water, l	cement	crushed stone	sand	crushed stone	sand	
1	200	395	1132	640	–	–	2367
2	214	421	1123	–	–	752	2510
3	192	380	–	645	1165	–	2382
4	200	389	–	–	1165	623	2377

During the experiment is was established that concrete made of ferrochrome slagin the form of coarse and fine aggregates possesses, higher strength characteristics (table6). Since as it was indicated above slag has more developed surface and due to this cohesion of aggregate and binder or binding material improves. Due to water suction by porous aggregate cement slurry penetrates into open pores, as a result as if growing of cement stone and aggregates takes place. Water adsorbtion contributes to elimination of water films formation danger on the surface of aggregates which hinder cohesion.

Table 6. Physic-mechanical properties of concrete.

Content No	Density, kg/m^3	Compressive strength, MPa in a day			Class
		3	7	28	
1	2358	14.8	25.2	28.3	B20
2	2500	17.2	23.6	30.4	B20
3	2378	12.6	20.9	34.3	B25
4	2372	13.5	23.9	43.0	B30

4. Conclusion

Ferrochrome slag due to its physic-mechanical properties meets Russian Standard 3344–83 and 5578 requirements. It can be utilized both crushed stone in road building and coarse and fine aggregate in concrete production. Concretes made of ferrochrome slag conform Russian Standard 26633 and have higher density and strength than concretes made of traditional materials, they refer to B25-B30 class. The replacement of granite crushed stone by ferrochrome one results in Portland cement consumption reduction decreasing or reducing concrete cost price.

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